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# CHEMICAL/PHYSICAL AND BIOLOGICAL TREATMENT OF WOOL PROCESSING WASTES

Lester T. Hatch, et al

Metcalf and Eddy, Incorporated

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EPA-660/2-73-036
January 1974

# CHEMICAL/PHYSICAL AND BIOLOGICAL TREATMENT OF WOOL PROCESSING WASTES

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## ABSTRACT

Elevated temperature acid-cracking combined with pilot activated sludge and lagoon treatment were utilized to treat effluent wastewater from a woolen processing plant. Effluent from woolen "top" (raw wool scouring) making is very high in BOD, COD, and suspended solids (18,880 ppm, 60,600 ppm, 37,600 ppm, respectively). The chemical/physical system consisted of a hot acid-cracking process to reduce the grease content in the influent to the biological system. Average grease reductions were from 13,400 ppm to 120 ppm or 99 percent with a BOD reduction of 70 percent and COD reduction of 80 percent. The biological system consisted of a pilot extended aeration activated sludge unit with clarification and retention in a pilot facultative lagoon (53 days' retention). Typical BOD and COD reductions in the activated sludge/clarification unit were 83 percent and 54 percent, respectively, and in the lagoon 56 percent and 54 percent, respectively.



This report was submitted in fulfillment of Grant No. 12130 HFX under the sponsorship of the Office of Research and Development, United States Environmental Protection Agency.

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Dr. James T. O'Rourke directed the project for Metcalf & Eddy. Additional direction and supervision were provided by Dr. Ronald Sharpin and Mr. Wayne Wirtanen. The design, construction, operation, and evaluation were the responsibility of Mr. Leslie T. Hatch.

# SECTION I

## CONCLUSIONS

1. Biological treatment of hot acid-cracked wool scour wastewater will reduce BOD, COD and suspended solids by 96, 78 and 62 percent, respectively.

2. Based on a comparison between the pilot plant performance and the draft proposed guidelines for waste discharges of the textile industry, the effluent containing 6.2-8.2 kilograms (kg) of $BOD_5$/1,000 kg of product (wool top) and 2.6-5.1 kg of total suspended solids/ 1,000 kg of product would be acceptable for discharge.

3. Hot acid-cracking removes 99 percent of the grease present in the raw scour liquor.

4. Because of the waste's high oxygen demand, low alpha value, and the increased biological activity resulting from warm water temperatures in the summer, very high oxygen input must be made to maintain a dissolved oxygen (DO) concentration of 1-2 mg/L in the aeration tank.

5. Because of the wastewater's low oxygen transfer coefficient, 20 days' detention time in the aeration tank is required rather than the design time of 10 days.

6. Settling tanks used for grease separation after hot acid cracking must operate on a batch basis rather than in a continuous flow mode to provide adequate cooling and settling.

7. Sludge drying beds are superior to lagooning, vacuum filtration or centrifugation for dewatering waste biological sludge.

## SECTION II

## RECOMMENDATIONS

1. More effort should be made to limit the amount of acid used in the cracking process, thereby reducing the amount of lime required. This would lower operating cost and lower the dissolved solids concentrations.

2. Further studies are recommended to investigate the removal of phosphorus and, more importantly, nitrogen using chemical and/or biological processes.

3. The secondary clarifier should be sized using a conservative overflow rate of 8.14 $m^3/m^2$/day (200 gpsf/day).

4. Additional study should be directed to determining adequate methods of color removal using activated carbon, chemical conditioning or possibly polymer adsorbents.

5. A reliable foam control system is needed to limit foaming in the aeration basin; this is especially important in cold weather when foaming is more of a problem.

6. Further research is needed to determine what coagulants and/or coagulant aid(s) will satisfactorily reduce suspended solids in the secondary clarifier effluent.

7. Softening or ion exchange studies are recommended to lower the dissolved solids concentrations.

8. Methods of further BOD, COD, and suspended solids removal such as multistage extended aeration, aeration of the final lagoon, chemical/physical removal or treatment with activated carbon should be considered for additional study.

## SECTION III

## INTRODUCTION

In the scouring of raw wool, there are two major wastewater streams; the scour water and the rinse water. The scour water is the stronger of the two wastewater streams since it carries most of the dirt, grease, and excrement contained in the raw wool. The rinse water, which serves to remove the detergent from the wool, is considerably weaker (see comparison Table 1).

Table 1. TYPICAL BARRE WOOL SCOURING WASTE COMPOSITION

| | Scour water | Rinse water |
|---|---|---|
| Biochemical oxygen demand, mg/L | 18,880 | 390 |
| Chemical oxygen demand, mg/L | 60,600 | 1,560 |
| Suspended solids, mg/L | 37,600 | 780 |
| Total Kjeldahl nitrogen, mg/L | 900 | 50 |
| Ammonia nitrogen, mg/L | 160 | 5 |
| Total phosphorus, mg/L | 60 | 4 |
| Grease, mg/L | 13,300 | 130 |
| pH | 7.0-8.2 | 6.0-8.7 |

Most efforts to treat the wastes from raw wool scouring processes have been aimed at recovering the wool grease. The grease is a source of lanolin as well as being a proprietary source of base oils used in tanning preservative compounds.[1, 2] In order to remove the grease, one of three methods is commonly used:

1. Chemical cracking, using acids or salts

2. Centrifuging

3. Solvent extraction.

With the increased use of nonionic detergents in the past two decades, the acid or salt cracking processes have become more attractive. The grease-water emulsion formed by the nonionic detergents is more difficult to break than the emulsion formed when a mixture of soda ash and soap is used for scouring. The chemical cracking more satisfactorily breaks this emulsion.[3, 4]

The need for further treatment has become more pressing with the increasing concern for protecting our environment. Ambient, facultative lagoons have been used to treat the waste prior to discharge to receiving streams.[5, 6] The technique of discharging to domestic sewerage systems for treatment has been recommended.[7, 8] The trend of combining industrial and domestic wastes for treatment has also been adopted with the proposal of anaerobic digestion of the wool scouring waste prior to treatment along with domestic sewage at domestic trickling filter plants.[9, 10, 11] Progress, however, continues to center around grease recovery more than trying to solve the overall pollution problem.

In December 1969, Metcalf & Eddy submitted a report to the Town of Barre, Massachusetts, suggesting that a sewage treatment plant be constructed which would handle a combination of domestic and very strong wool-scouring waste. In leading to this conclusion, bench scale activated-sludge units had been used to determine that the effluent from a new grease recovery system developed at the Barre Wool Combing Company could be treated biologically.

Based on the pilot studies, it was felt that operation of a larger pilot plant would clarify more fully the following issues:

1. Sustained treatment reliability.

2. Cold weather reliability of the biological system.

3. Possible nutrient deficiencies.

4. Any unforeseeable toxicity.

5. Design and operating parameters for a full-scale plant.

PROPOSED TREATMENT

The treatment of the wool-scouring wastewaters was to be conducted in two phases; a physical/chemical phase which would remove most of the grease and solids, and a biological phase to treat the remaining pollutants. The first phase of treatment was to be concerned primarily with treating the raw scour liquor to separate the grease. The biological process would treat the combined effluent from the grease removal operation and the raw rinse water.

Primary settling of the raw scour liquor would remove the coarser grit and solids. The supernatant would then be acidified using industrial grade (66 degrees Baume) sulfuric acid to a pH of 2-3. The acidified liquor would then be hot cracked by heating to a boil and being maintained at that temperature for one hour; after the boiling has broken the emulsion, cooling and settling would separate the grease and solids from the cracked scour liquor.

The decanted cracked scour liquor would be mixed with rinse water in a 60:40 ratio (essentially the same ratio as the present plant flow streams), and the resulting mixture would be neutralized to a pH of 4.5-5.5 using lime. In operating the pilot plant the neutralized mixture would be stored prior to feeding to the biological system thus maintaining sufficient feed material during periods of low plant flow (weekends when Barre Wool plant production was down).

The biological process would consist of an extended aeration lagoon with 10 days' detention. Following aeration, the settled effluent would be further lagooned for 53 days.

## SECTION IV

## DESCRIPTION OF PILOT PLANT

### CONSTRUCTION PHASE

Construction occurred in three phases:

1. Outdoor construction of concrete tanks and necessary earthwork.

2. Installation of motors, pumps, galleries, and electrical controls.

3. Installation of acid-cracking tank, heat exchangers, and all connecting plumbing for all units.

The completion of Phases 1 and 2 occurred on time. Phase 3 took longer than expected due to problems encountered when installing heat exchangers and the delay caused by late material delivery. Total construction for all three phases consumed 12 weeks.

Particular care was taken in designing and constructing the aeration tank, lagoon, and secondary settling tank. Preliminary site investigation indicated a high-groundwater table within 1.83 meters (m) (6 ft) of the surface during the spring. For this reason, the units were installed partially above ground to reduce the danger of floating in the spring.

To simplify construction, Schedule 80 Plastic Pipe Chlorinated Polyvinyl Chloride (CPVC) was used for all small feed, effluent, and sludge lines. The process piping for the acid-cracking portion of the plant was black iron in both Schedules 40 and 80, depending upon the application. Cor-Ten Steel was used for the two settling tanks. Reinforced-fiberglass tanks were used for mixing, neutralizing, and storing the feed. Type 316 stainless steel was used for the acid-cracking tank.

The major components of the pilot plant consisted of a 3.03 cubic meters ($m^3$) (800 gal.) cracking tank, a 9.08 $m^3$ (2,400 gal.) grease settling tank, four 7.57 $m^3$ (2,000 gal.) reinforced fiberglass plastic (RFP) storage tanks, a 75.7 $m^3$ (20,000 gal.) aeration tank, a 2.08 $m^3$ (550 gal.) secondary clarifier, a 45.42 $m^3$ (12,000 gal.) ambient lagoon, and a 7.57 $m^3$ (2,000 gal.) sludge lagoon. A complete inventory of units is included in Table 2.

Table 2. TABLE LISTING UNITS AND SIZES

| | | |
|---|---|---|
| 316 stainless-steel cracking tank | 3.03 $m^3$ | (800 gal.) |
| Grease settling tank | 9.08 $m^3$ | (2,400 gal.) |
| Mixing tank (RFP) | 7.57 $m^3$ | (2,000 gal.) |
| Storage tanks (RFP @ 7.57 $m^3$ (2,000 gal.) | | |
| Total storage | 22.71 $m^3$ | (6,000 gal.) |
| Mixer | 30.28 $m^3$ | (8,000 gal.) |
| Transfer pump | 2.24 kw | (3 hp) |
| Feed pump | 1.9 L/sec | (30 gpm) |
| Aeration tank | 0-0.13 L/sec | (0-2 gpm) |
| Aerators | 75.7 $m^3$ | (20,000 gal.) |
| Secondary settling tank | @ 0.56 kw | (2 @ 3/4 hp) |
| Return sludge/waste sludge pump | 2.08 $m^3$ | (550 gal.) |
| Storage lagoon | 0-0.13 L/sec | (0-2 gpm) |
| Storage lagoon feed pump | 45.42 $m^3$ | (12,000 gal.) |
| Sludge lagoon | 0-0.03 L/sec | (0-0.5 gpm) |
| | 7.57 $m^3$ | (2,000 gal.) |

The system was located in two separate areas of the Barre Wool Combing Company plant. The primary portion, consisting of the acid-cracking tank, grease settling tank, neutralizing and storage tanks was located inside the existing grease works facility. The biological part was located out-of-doors in an empty plot 180 m (600 ft) from the grease works. A schematic of the system is shown on Figure 1.

The wool scour waste was drawn out of the existing cold acid-cracking tank and passed through a preheater before being fed into the stainless-steel cracking tank. The hot acid cracking was accomplished by using stainless-steel steam coils within the tank and heating the scour waste to a boil. Steam resulting from this boiling was exhausted into a condenser located above the cracking tank which permitted condensate to return to the cracking tank. This prevented any reduction in waste volume and resultant increase in waste strength, and also prevented air pollution.

Following hot acid cracking, the waste flow was cooled in a heat exchanger before being dumped into the grease settling tank. After settling, an adjustable drain permitted the supernatant, the cracked scour liquor, to be drawn off for mixing with rinse water and neutralizing. The grease sludge produced was pumped out the bottom of the settling

tank and discharged into one of the existing Barre Wool grease plant settling tanks for treatment in their existing grease extraction facility.

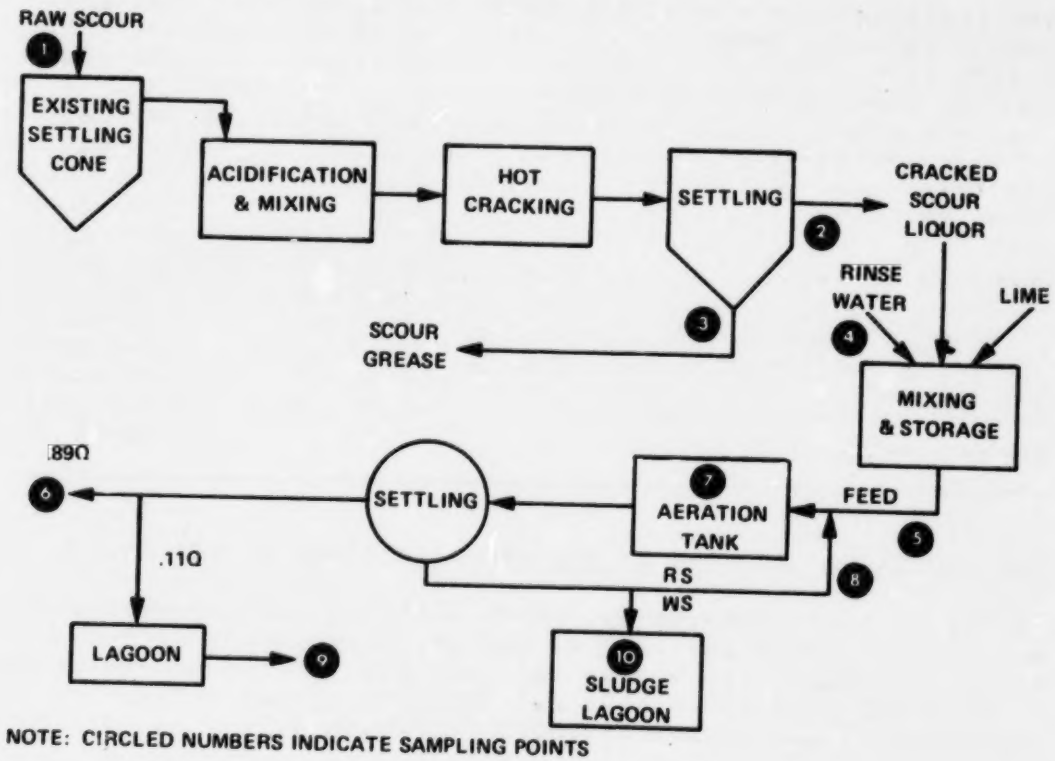


FIG. 1 SCHEMATIC OF TREATMENT SYSTEM

Supernatant from the grease settling tank was dumped into one of the 7.57 $m^3$ (2,000 gal.) reinforced-fiberglass storage tanks where it was mixed with the rinse water. This mixture's pH was then adjusted to 4.5-5.5 by adding lime while mixing. Upon completion of neutralization, the waste was then transferred to one of the other three tanks for storage until being fed to the aeration tank.

The aeration tank was designed to provide equal mixing zones of 4.27 m by 4.27 m x 2.29 m (14 ft by 14 ft by 7.5 ft) deep around each of the two aerators. This optimized the mixing zones according to the manufacturer's data. The aerators used were submersible motors with impellers which pumped the mixed liquor up a draft tube to a sparger plate. A total of 1.12 kilowatt (kw) (1.5 hp) of aerator capacity was used.

Overflow from the aeration tank proceeded into the secondary clarifier. No scraper mechanism was provided since the tank was designed with steep conical walls (1:1 slope) at its base. This provided for good transport of the settled solids to the center sludge withdrawal pipe. The weir plate had four equally spaced 60-degree V-notches. Underflow from this clarifier could either be returned to the influent end of the aeration tank or pumped to the sludge lagoon. The clarifier overflow passed into a flow splitter designated as a sump.

Eighty-nine percent of the clarifier overflow passed through the sump and out of the system. The remaining 11 percent was pumped into the storage lagoon. Following ambient lagooning for 53 days, this flow was also discharged from the system.

Waste sludge was lagooned prior to disposal in the sludge lagoon. Only if the lagoon's capacity was exceeded would sludge be disposed of on land. If this were necessary, the sludge would be trucked to a land disposal site presently used by Barre Wool for sludge disposal.

The basic design parameters for the biological system were determined in two ways. The completely mixed aeration tank design was based on the results of the bench units tested in 1969 as previously mentioned. The lagoon design was based solely on lagoon volumes which Barre Wool presently has available. These design values are listed in Table 3.

Table 3. DESIGN PARAMETERS OF BIOLOGICAL SYSTEM

| | |
|---|---|
| F/M | 0.03-0.05 |
| BOD loading | 74-83 grams/$m^3$/day (15-17 lb/1,000 cf/day) |
| Aeration detention time | 10 days |
| Return sludge | 100-200 percent of the influent flow |
| Alpha | 0.75 |
| Beta | 0.95 |
| Lagoon detention time | 53 days |

## SECTION V

## SAMPLING AND ANALYSIS

Since the pilot plant was operated in two different modes, batch in the acid-cracking operation, and continuous in the biological operation, separate sampling techniques were applied. During the preparation of feed for the pilot plant, samples were taken at points 1, 2, 3, and 4 (see Figure 1). These were grab samples taken as the various steps in the batch process hot acid cracking were performed.

The biological units, being fed continuously, were sampled continuously at points 5, 6, 8, and 9 using an arrangement as shown on Figure 2.

Samples from points 5, 6 and 8 were taken from lines under pressure due to pumping. The rate of sample collection was controlled by pinchcocks on the tygon tubing. Sample location No. 9 was under only a very slight hydrostatic pressure but still required a pinchcock to control the sampling rate.

The sampling from point 7 was a daily grab sample. It was taken between the two aerators at a point of good mixing.

Sampling point 10 was not used until the end of the study when lagooned sludge was sampled for grease and solids.

A list of tests conducted on each flow stream is shown in Table 4. Testing frequency was initially set at 1-3 times weekly; however, during the study, most tests were performed 3-5 times weekly.

### TESTING PROCEDURES

#### Total Solids, Total Volatile Solids, Suspended Solids, and Volatile Suspended Solids

The procedures suggested by "Standard Methods"[12] were followed: The only deviation occurred when determining total solids for samples having a pH less than 4.3. "Standard Methods" recommends that when samples have a pH below 4.3, a solution of 1N sodium hydroxide, NaOH, be added to the sample to maintain a pH greater than 4.3 during evaporation. This procedure would have applied to Samples 2 and 3,

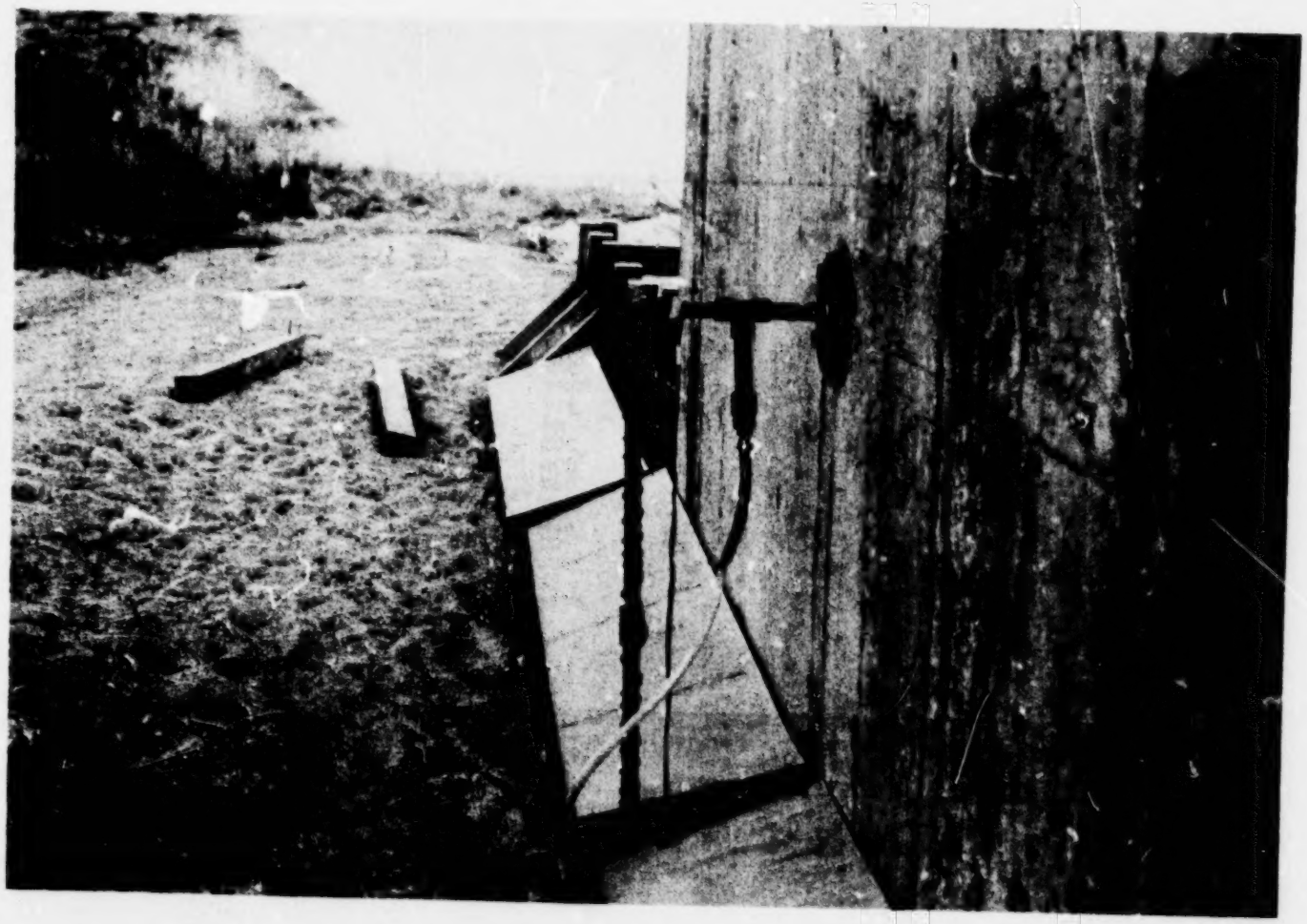

FIG. 2 SAMPLING PORT OF BIOLOGICAL UNIT

## Table 4. SAMPLING POINTS AND TESTS PLAN

| Stream name | Raw scour | Acid cracked scour liquor | Scour grease | Rinse water | Aeration tank influent | Aeration tank settled effluent | Aeration tank mixed liquor | Return sludge | Lagoon effluent | Lagoon sludge |
|---|---|---|---|---|---|---|---|---|---|---|
| Sampling point No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Measurements and analysis performed | Flow | Flow | Flow | Flow | Flow | - | - | Flow | - | Flow |
| | TS | TS | TS | TS | TS | TS | TS | TS | TS | - |
| | TVS | TVS | TVS | TVS | TVS | TVS | TVS | TVS | TVS | - |
| | SS | SS | - | SS | SS | SS | SS | - | SS | - |
| | VSS | VSS | - | VSS | VSS | VSS | VSS | - | VSS | - |
| | Set. sol. | Set. sol. | - | Set. sol. | Set. sol. | Set. sol. | Set. sol. | - | Set. sol. | - |
| | BOD | BOD | - | BOD | BOD | BOD | - | - | BOD | - |
| | COD | COD | - | COD | COD | COD | - | - | COD | - |
| | TOC | TOC | - | TOC | TOC | TOC | - | - | TOC | - |
| | pH | pH | pH | pH | pH | pH | pH | - | - | - |
| | ALK | ALK | - | ALK | ALK | ALK | - | - | - | - |
| | Acid | Acid | - | Acid | Acid | Acid | - | - | - | - |
| | TKN | TKN | - | TKN | TKN | TKN | - | - | TKN | - |
| | $NH_3$-N | $NH_3$-N | - | $NH_3$-N | $NH_3$-N | $NH_3$-N | - | - | $NH_3$-N | - |
| | $NO_3$-N | $NO_3$-N | - | $NO_3$-N | $NO_3$-N | $NO_3$-N | - | - | $NO_3$-N | - |
| | $NO_2$-N | $NO_2$-N | - | $NO_2$-N | $NO_2$-N | $NO_2$-N | - | - | $NO_2$-N | - |
| | Total P | Total P | - | Total P | Total P | Total P | - | - | Total P | - |
| | Grease | Grease | Grease | Grease | - | - | - | - | - | - |
| | PNS | PNS | - | PNS | - | - | - | - | - | - |
| | - | - | - | - | - | - | DO | - | DO | - |
| | - | - | - | - | - | - | Temp. | - | Temp. | - |

the Acid Cracked Scour Liquor and Scour Grease. The potential loss of volatile material at the low pH during evaporation was insignificant compared to the total solids concentration of the samples, so the recommended procedure was not followed.

Because of the high volatile organics concentrations present as grease and fatty acids, there was an inherent error in all of the solids determinations. It is safe to say that the samples do not dry to constant weight at the desired test temperatures because of the different evaporation rates of the various volatile compounds present. This applies to Samples 1 and 4, the Raw Scour and Rinse Water, as well as Samples 2 and 3. During the study, the error in solids determinations was assumed to be negligible for all samples and no corrections were made.

BOD

The membrane electrode modification as suggested in "Standard Methods" was used for the BOD. A Yellow Springs Instrument Model 54 Portable Dissolved Oxygen Analyzer was used with a self-stirring probe. An acclimated seed of mixed liquor was used in the dilution water. Because of manpower requirements, a 7-day test was used instead of the normal 5-day test. A factor of 0.87 related the 7-day BOD to the 5-day BOD. All data in this report are reported as 5-day BOD.

COD

The Dichromate Reflux Method of determining COD as outlined in "Standard Methods" was followed.

TOC

Tests were run using a Beckman Total Organic Carbon Analyzer as "Standard Methods" suggests. The samples were filtered through Whatman No. 40 paper to remove large particles. Because of the high-grease content, filter binding occurred and some loss of accuracy resulted. Sample 1, The Raw Scour Liquor, was most susceptible to binding.

pH, Alkalinity, Acidity

The same procedures as outlined in "Standard Methods" were utilized using a Beckman pH meter. Deviation from "Standard

Methods" was made in determining the pH of Samples 1 and 3, The Raw Scour Liquor and Cracked Scour Grease. Instead of using the pH meter, pH indicating paper was used. This limited pH results to an accuracy of not better than +1 pH unit. This action was necessary because of repeated pH electrode failures after taking pH measurements in these two high-grease content streams. Efforts to thoroughly clean the electrode as suggested by the manufacturer were not successful and contributed to shorter electrode life. For these reasons, the pH indicating paper was used.

Nutrients

Total Kjeldahl nitrogen, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, and total phosphorus levels were determined using tests outlined in "Standard Methods." A Bausch and Lomb "Spectronic-20" spectrophotometer was used for the colorimetric analysis and the Beckman pH meter was used for titrations. To eliminate interfering color in the tests for nitrate, nitrite, and phosphorus, samples were treated using "Darco KB" activated carbon.

Grease

The approaches suggested in "Standard Methods," Sections 209A and 209C were followed. The solvent used was petroleum ether rather than n-Hexane or trichlorotrifluoroethane. The petroleum ether was used because of its lower boiling point which allowed refluxing to begin quicker and also shorten evaporation time at the end of the test. In addition, oil and grease are extracted to the same extent by either petroleum ether or trichlorotrifluoroethane.

Surfactants

Since the Barre Wool Combing Company uses a nonionic detergent, the tests suggested in "Standard Methods" which is specific for anionic surfactants could not be used. However, the procedure developed by Crabb and Persinger[13] for polyoxyethylene nonionic surfactants was applicable. The following is an outline of the procedure used:

1. Place sample in 500-milliliter (ml) separatory funnel.

2. Add 25 ml of diethyl ether and shake. If ether layer does not separate, add 1 gram potassium chloride and shake again.

3. Draw water layer into a clean beaker and filter other layer through Whatman No. 1PS paper into a 125-ml separatory funnel.

4. Repeat steps 2 and 3 until 100 ml of diethyl ether is used.

5. Evaporate ether in hot water bath.

6. Add 5 ml ammonium cobalt thiocyanate solution and shake.

7. Add 15 ml chloroform and shake.

8. Draw off chloroform layer through Whatman No. 1PS paper into a 25-ml graduated cylinder.

9. Repeat chloroform extraction with 5 ml and 6 ml of chloroform. Add enough carbon tetrachloride ($CCl_3$) to make up 25 ml.

10. Read at 620 millimicrons (mμ).

Color

The color procedure as outlined in "Standard Methods" was used. Also a stream dilution study was run. The pilot plant lagoon effluent was diluted to the point at which no color difference could be detected between existing river water and the dilutions.

Alpha Value

Alpha, or the relative oxygen transfer coefficient, was determined using an adaptation of a procedure suggested by Sawyer.[14] The equipment used is shown on Figure 3. The procedure which follows was used for both distilled water and wastewater.

1. Aerate sample at a constant temperature to point of dissovled oxygen saturation; record saturation, DO and temperature.

2. Draw a 700-ml sample of water into a 1,500-ml flask.

3. Add 0.75 ml of cobalt chloride solution (1 ml = 5 mg $CoCl_2$).

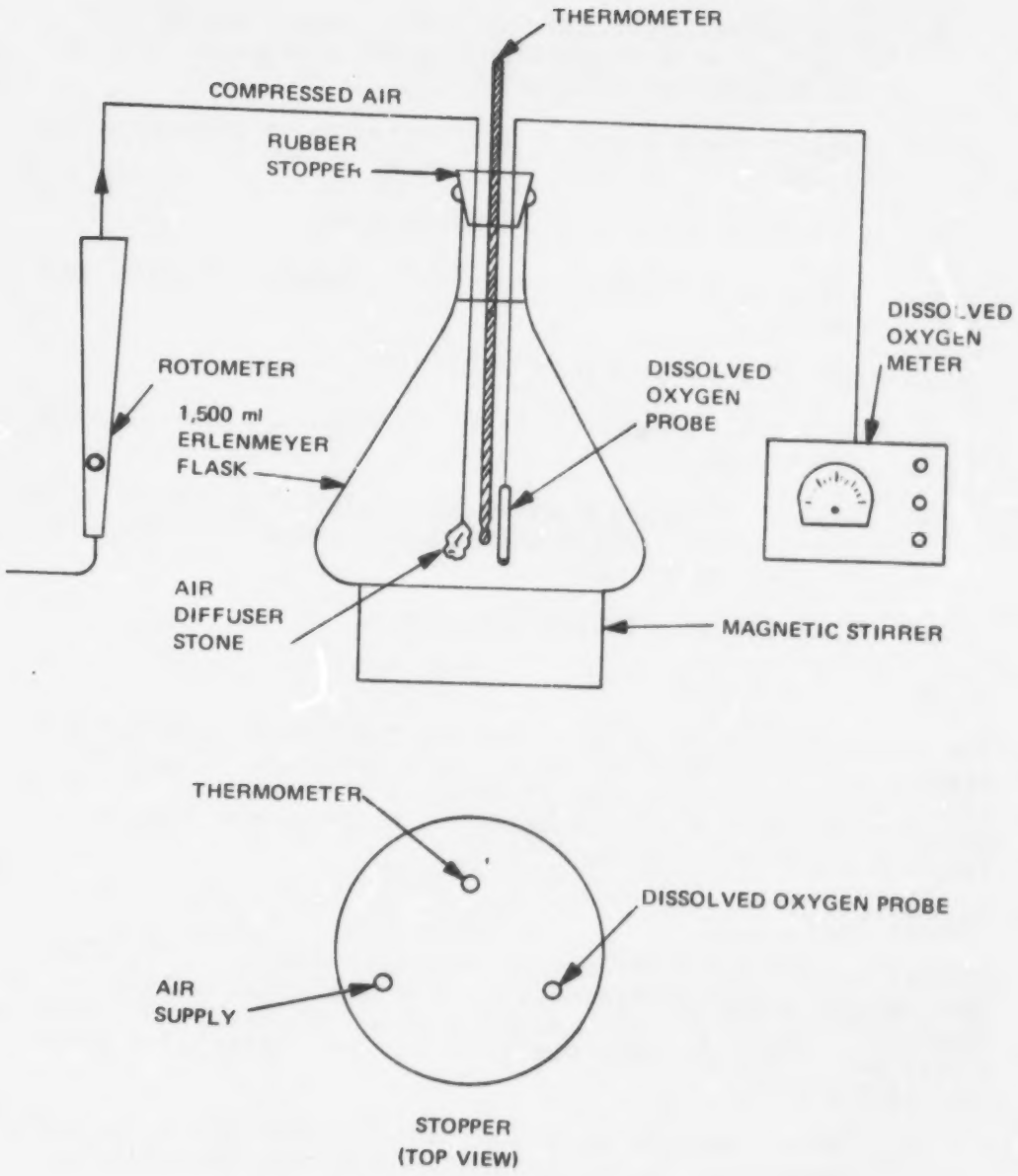


FIG. 3 SCHEMATIC OF APPARATUS FOR ALPHA AND BETA MEASUREMENT

4. Add 0.06 grams sodium sulfite powder.

   Note: Amounts indicated in 3 and 4 may be adjusted up or down to achieve zero DO.

5. Place flask on magnetic stirrer and mix until all powder and solution are thoroughly dispersed. DO should now be zero.

6. Turn off mixer and insert stopper with metered air supply, DO probe, and thermometer.

7. Begin aerating at a constant rate, start timer when first air bubbles reach liquid surface.

8. Continue aerating and record DO concentration and temperature at 3-minute intervals.

9. Continue aerating and collecting data until DO level approaches saturation.

Calculation of $K_w$ and $K_{ww}$ rate coefficients of oxygen absorption for tap water and wastewater, respectively, can be done using the following formula:

$$K_w = (\log D_1 - \log D_2)\ 2.3/(t_2 - t)$$

where:

$K_w$ = Rate of oxygen absorption in mg/L per hour per mg/L DO deficiency.

$t_1$ = Elapsed time hours to first DO deficiency reading used in calculation.

$t_2$ = Elapsed time in hours to second DO deficiency reading used in calculation.

$D_1$ = Oxygen deficiency at time $t_1$.

$D_2$ = Oxygen deficiency at time $t_2$.

Similarly, $K_{ww}$ can be calculated.

From this, alpha can be determined using the following relationship:

$$\alpha = K_{ww}/K_w$$

A word of caution, all values should be corrected to some standard temperature, preferably 20 deg C.

Beta Value

The beta value is the ratio of the DO concentrations in the wastewater at saturation to the DO concentration in distilled water at saturation. Both values used should be corrected to some constant temperature.

## SECTION VI

## OPERATION AND ANALYSIS

### OPERATION

The operation and evaluation of the pilot plant was divided into three phases:

1. Startup and acclimation, March 8-August 28, 1973
2. Warm weather, August 29-November 16, 1972
3. Cold weather, November 17, 1972-January 5, 1973.

### STARTUP

The comparatively long startup period of 6 months should be explained. Attempts to start a biological system in very cold weather are normally unsuccessful. Since cold weather evaluation was a prime purpose of this project, a study was made of the efforts to develop the biological system under adverse temperature conditions. The cold weather startup period ran from early March to early July, a period of 4 months. The warm weather startup phase, the 2 months from July to September, was more productive than the previous 4 months' efforts as far as producing a growing microbiological population. However, the efforts expended in the first 4 months should be discussed.

### COLD WEATHER STARTUP

During early March 1972, rinse water was pumped into the aeration tank and the aerators were placed in operation. During this period, a composite of four 1-liter samples was taken at different locations along the length of the aeration tank. The results of the analysis of this sample are shown in Table 5.

Icing conditions existed in the aeration tank, with large blocks of ice forming on the aerator tethering ropes. The secondary clarifier was often inoperative due to a thick layer of surface ice.

Initially, an attempt was made to start the plant without seeding. Following three weeks' aeration and feeding with

rinse water, suspended solids data indicated no increase in the mixed liquor suspended solids level over the initial 200 mg/L.

Table 5. CHARACTERISTICS OF AERATION TANK CONTENTS OF STARTUP

| | | |
|---|---|---|
| pH | 7.8 | |
| Total alkalinity | 145 | mg/L as $CaCo_3$ |
| SS | 194 | mg/L |
| VSS | 140 | mg/L |
| TKN | 24 | mg/L |
| Total phosphorus | 3.76 | mg/L |
| BOD | 260 | mg/L |
| Temp. | 0.4 | deg C |

At this point, late March 1972, a 3.8 $m^3$ (1,000 gal.) seed of domestic septic tank pumpings was fed into the aeration tank. The suspended solids level was near 1,000 mg/L immediately following the seeding. The feeding of rinse water was maintained following this seeding. This mode of operation continued into mid-April, with no increase in suspended solids. There was no sludge returned during this period due to a lack of settleable solids.

With no increase in mixed liquor suspended solids, a change in feed was initiated in an effort to provide more food for the system. Cracked wool scour liquor was mixed with rinse water and neutralized to pH 7+ in the ratio of 95 percent rinse water to 5 percent cracked scour liquor. Over a two-week period, this ratio was increased until in early May, the feed was 60 percent cracked scour liquor and 40 percent rinse water.

The mixed liquor suspended solids continued to hover near 1,000 mg/L even after feeding the higher BOD mixture. A second seeding was attempted again using domestic septic

tank pumpings. Following this, two weeks' feeding produced no measureable increase in mixed liquor suspended solids concentration.

In an attempt to conserve suspended solids and achieve growth, the feeding schedule was changed from continuous feed to a batch feed operation in mid-May. This was accomplished by shutting down the aerators each second morning for one hour to allow settling in the aeration tank. Then, from 0.8 to 1.6 $m^3$ (200-400 gal.) of feed was pumped into the aeration tank displacing only the supernatant. Following feeding, the aerators were again turned on. This method did not increase mixed liquor suspended solids concentration. After two weeks, continuous feeding was resumed. This operation continued through June 1972.

WARM WEATHER STARTUP

As expected, with warmer water temperatures in early July, the system began to develop. Prior to July, the water temperature had risen steadily to 15 deg C, the mixed liquor had 7-8 mg/L dissolved oxygen. However, the mixed liquor suspended solids had only climbed to 1,200 mg/L. In July, the water temperature was 20-24 deg C, the mixed liquor dissolved oxygen dropped to 0.5 mg/L, and the mixed liquor suspended solids increased steadily from 1,200 mg/L to 3,900 mg/L. Although the BOD loading remained constant at 42.5 grams/$m^3$/day (9 lb/1,000 cf/day), the F/M ratio decreased steadily from 0.1 to the design ratio of 0.03-0.05 as the mixed liquor suspended solids concentration increased.

During the startup period, two specific subjects were considered. First, a study was conducted to determine how the BOD was exerted, and secondly, attempts were made to increase the mixed liquor dissolved oxygen level. Twenty-one day BOD tests were performed. As shown on Figure 4, 80 percent of the 20-day BOD was exerted within the first 5 days, an indication that the waste as prepared and fed to the biological system was readily biodegradable. Since most of the nitrogen was in the organic form and the septic tank seed that was used was low in nitrifying organisms, no discernable nitrogenous oxygen demand appeared over the 21-day test period.

Efforts were begun to correct the low dissolved oxygen level as soon as the problem arose. The feed rate was reduced and even stopped for one 24-hour period without showing any increase in the mixed liquor dissolved oxygen level. This

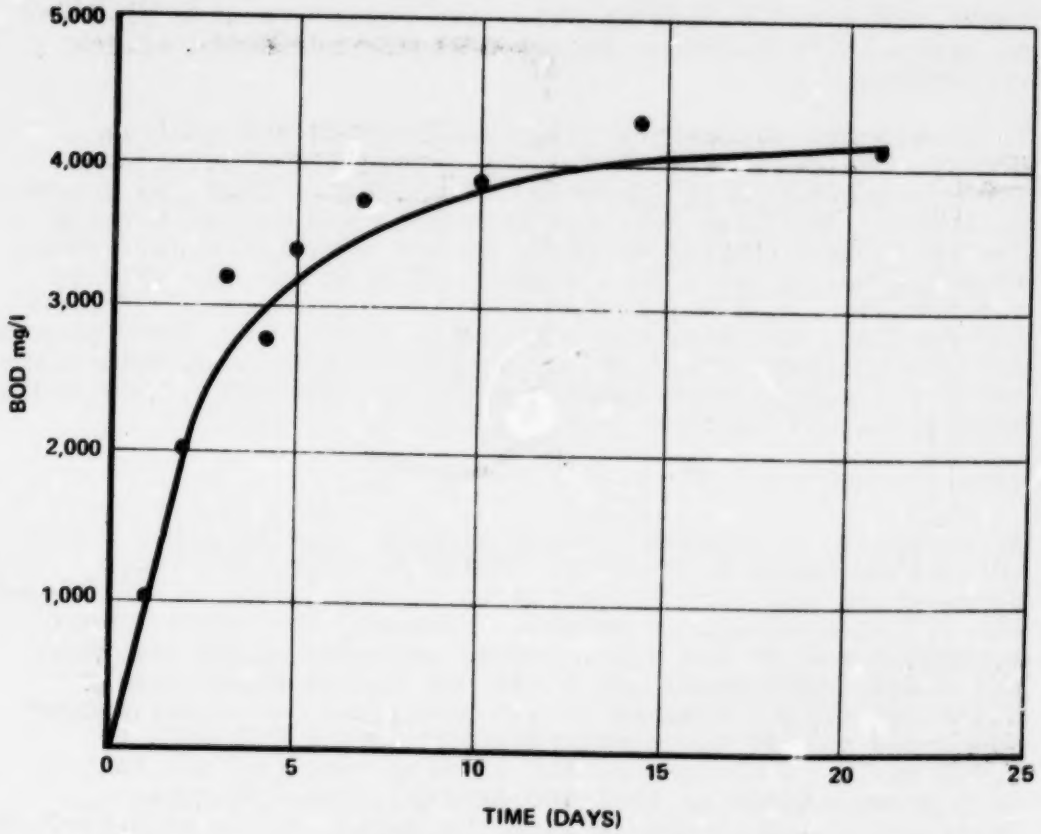


FIG. 4 BOD VS. TIME

condition of low dissolved oxygen was aggravated further by aerator failures which cut the system's oxygenating and mixing capacity by 50 percent. To supplement the aerators, compressed air was introduced below the draft-tube of the mechanical aerators using low-pressure air lines as shown on Figure 5. This arrangement introduced an additional 46 kg (100 lb) of oxygen to the aeration tank each day. While using this "Hybrid" system of mechanical and diffused aeration, the system continued to operate at a dissolved oxygen level of 0.5 mg/L. This condition of low dissolved oxygen was very noticeable during the latter part of start-up when septic odors and a black mixed liquor were predominant at the aeration tank.

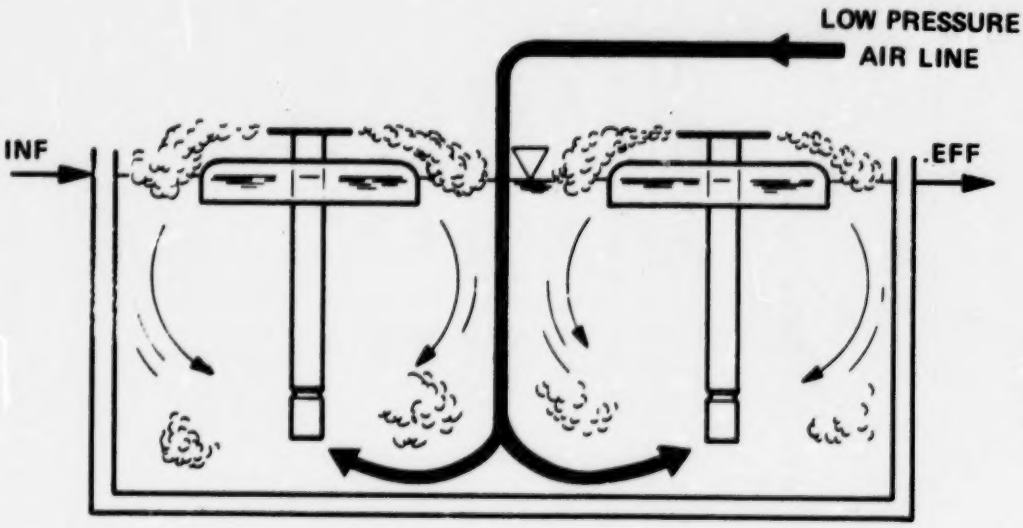


FIG. 5 AERATORS AND SUPPLEMENTAL AIR SUPPLY

The startup phase did reveal three facts about the waste which differed considerably from the original bench-scale pilot testing conducted in Metcalf & Eddy's laboratory in 1969.

1. The waste had a much lower alpha coefficient than originally assumed which required much larger aerators and $O_2$ supply.

2. The oxygen requirements were much higher than anticipated due to this higher oxygen requirement.

3. Chemical treatment created a very high level of fixed dissolved solids.

The combination of lower alpha and beta and high fixed dissolved solids concentration contributed significantly to the inability to maintain a 1-2 mg/L dissolved oxygen concentration in the mixed liquor.

WARM AND COLD WEATHER OPERATION

For ease of comparison, the warm and cold weather phases will be discussed simultaneously.

Table 6. TYPICAL AERATION TANK INFLUENT CHARACTERISTICS, mg/L

| | Entire study period | | | Warm study period | | | Cold study period | | |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Ave. | Max. | Min. | Ave. | Max. | Min. | Ave. |
| TS | 27,600 | 13,500 | 18,260 | 27,600 | 14,500 | 18,910 | 17,800 | 13,500 | 15,610 |
| SS | 1,720 | 130 | 380 | 880 | 130 | 340 | 1,720 | 190 | 300 |
| BOD | 3,830 | 1,740 | 2,840 | 3,830 | 1,890 | 2,930 | 3,010 | 1,740 | 2,420 |
| COD | 10,450 | 5,600 | 7,560 | 10,450 | 5,600 | 7,750 | 8,100 | 5,600 | 6,560 |
| TKN | 623 | 204 | 420 | 623 | 306 | 420 | 376 | 204 | 310 |
| $NH_3$ | 220 | 106 | 160 | 220 | 106 | 160 | 183 | 138 | 150 |
| Total P | 50 | 8.7 | 27.4 | 50 | 12.8 | 28.3 | 28.8 | 8.7 | 18.5 |

Due to the approaching cold weather, it was necessary to begin collecting the warm weather data even though the oxygen deficiency still existed. It is preferable to operate an activated-sludge system with a mixed liquor dissolved oxygen level of 1-2 mg/L. At the start of the warm weather period, the mixed liquor dissolved oxygen level was 0-0.5 mg/L. If higher oxygen concentrations could have been maintained during the entire warm study period, it is reasonable to assume that performance would have been better.

During the warm weather period, influent to the aeration tank was slightly higher in BOD, COD, nitrogen, etc. than occurred during the cold weather period. This is shown by the data of influent waste characteristics in Table 6. A possible explanation for this change in waste characteristics is a change in the quality of wool processed.

The operating conditions for the warm and cold weather periods are listed in Table 7. It would have been desirable to operate the pilot plant under similar conditions of loading, detention time, and F/M ratio. However, severe freezing conditions prevented continuous feeding on two occasions in December. As a result, the cold weather period had a lower BOD loading and longer detention time. There was also a drop in mixed liquor volatile suspended solids; however, the loading was sufficiently lower to cause the F/M ratio to decrease.

Table 7. OPERATING CONDITIONS DURING WARM AND COLD WEATHER

| | Warm | Cold |
|---|---|---|
| BOD loading (grams/$m^3$/day) | 48.0 | 25.9 |
| F/M | 0.05 | 0.03 |
| Mixed liquor DO (mg/L) | 1.0 | 6.0 |
| Mixed liquor temp. (deg C) | 13 | 3.0 |
| Detention time (days) | 19 | 25 |

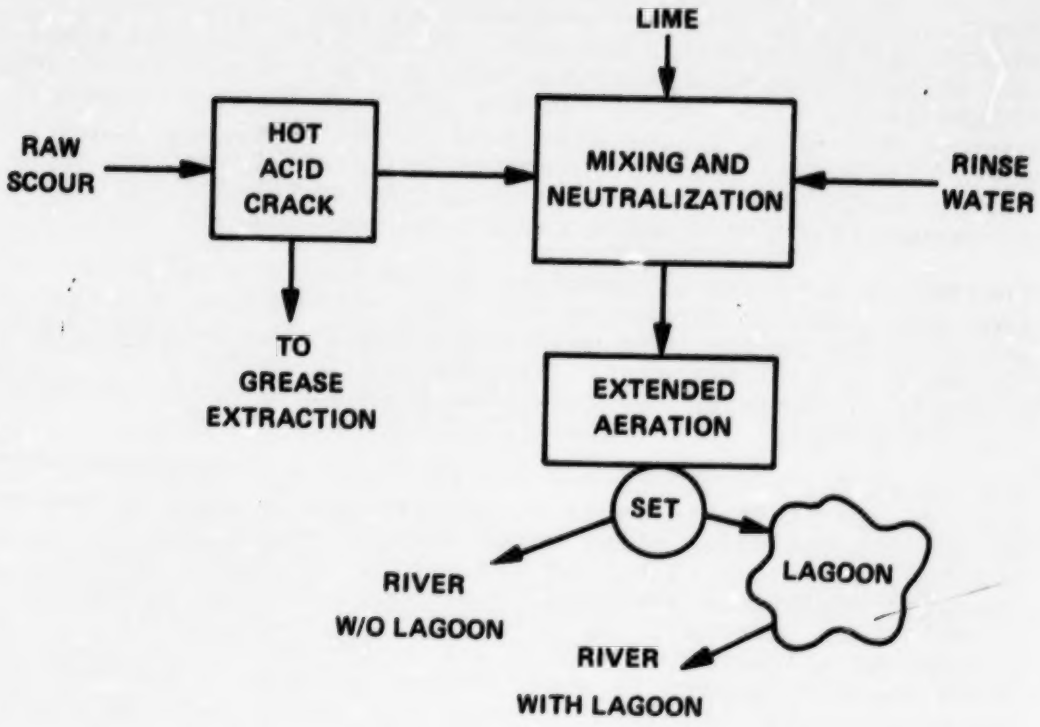


FIG. 6 SCHEMATIC OF PROPOSED TREATMENT

Performance of the biological pilot plant can be evaluated using the two options shown on Figure 6:

1. Aeration and settling without stabilization lagoon.
2. Aeration and settling with stabilization lagoon.

The levels of BOD, suspended solids, nitrogen, and phosphorus during warm and cold weather at various points in the treatment system including with and without the stabilization lagoon are shown on Figures 7 through 14.

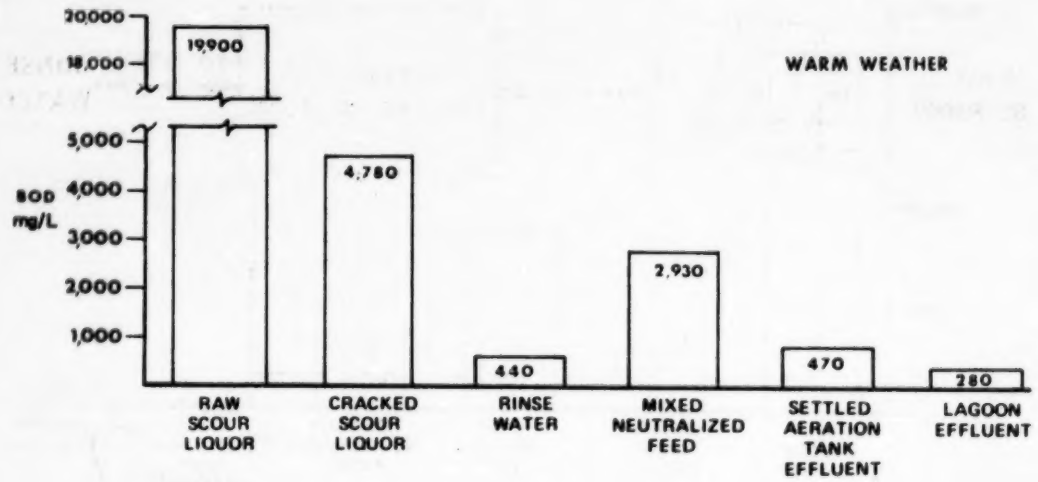


FIG. 7 BOD CONCENTRATION THRU SYSTEM (WARM WEATHER)

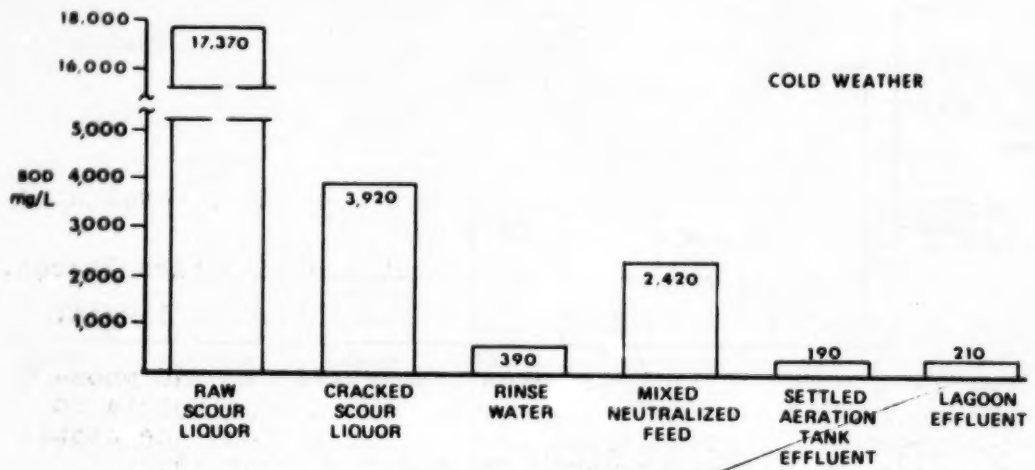


FIG. 8 BOD CONCENTRATION THRU SYSTEM (COLD WEATHER)

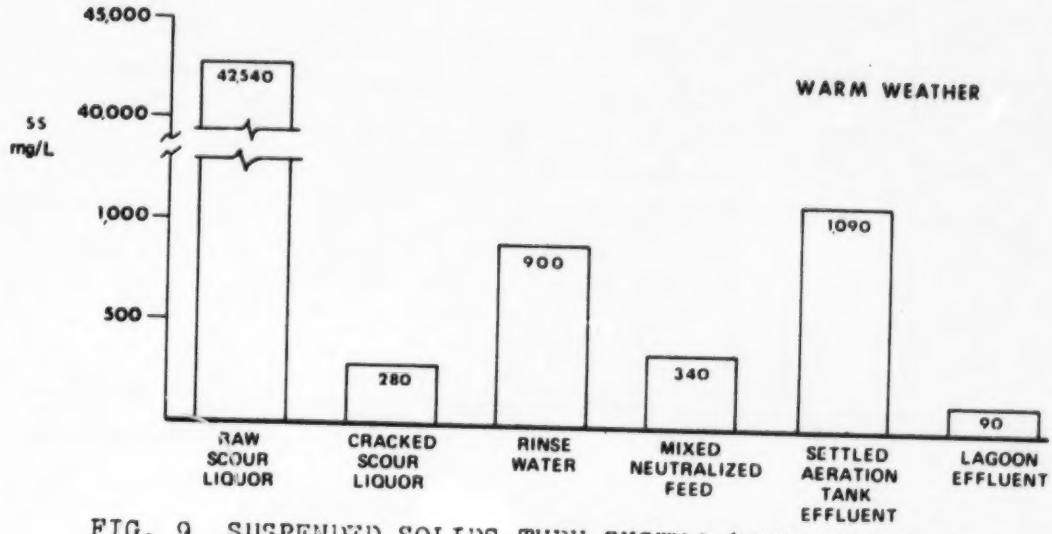


FIG. 9 SUSPENDED SOLIDS THRU SYSTEM (WARM WEATHER)

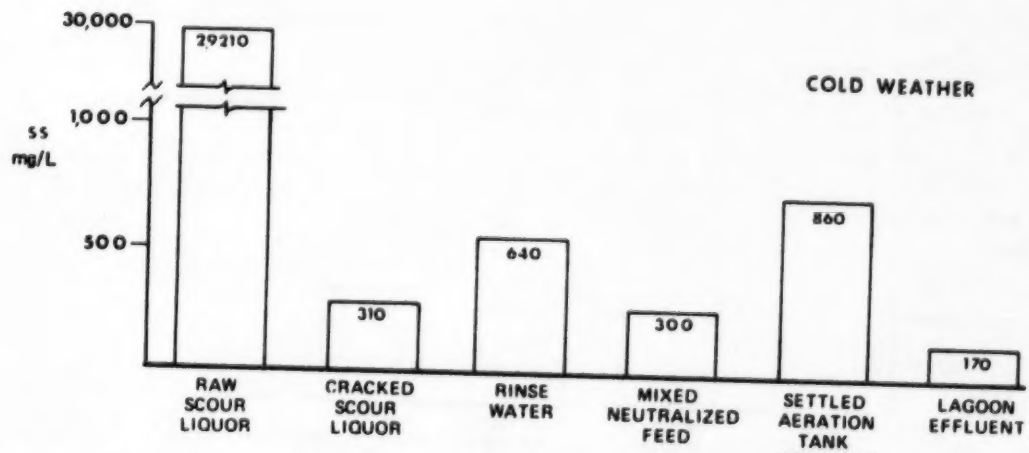


FIG. 10 SUSPENDED SOLIDS THRU SYSTEM (COLD WEATHER)

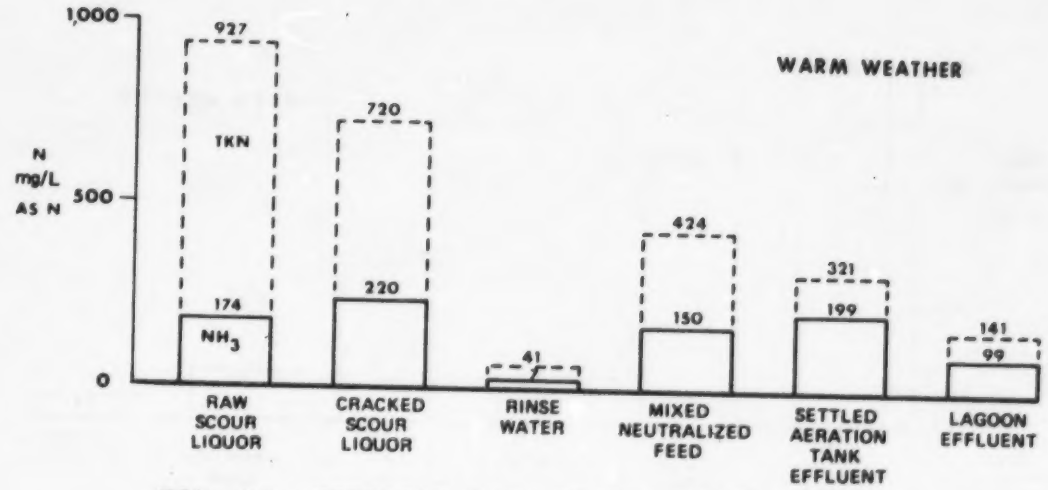


FIG. 11 NITROGEN THRU SYSTEM (WARM WEATHER)

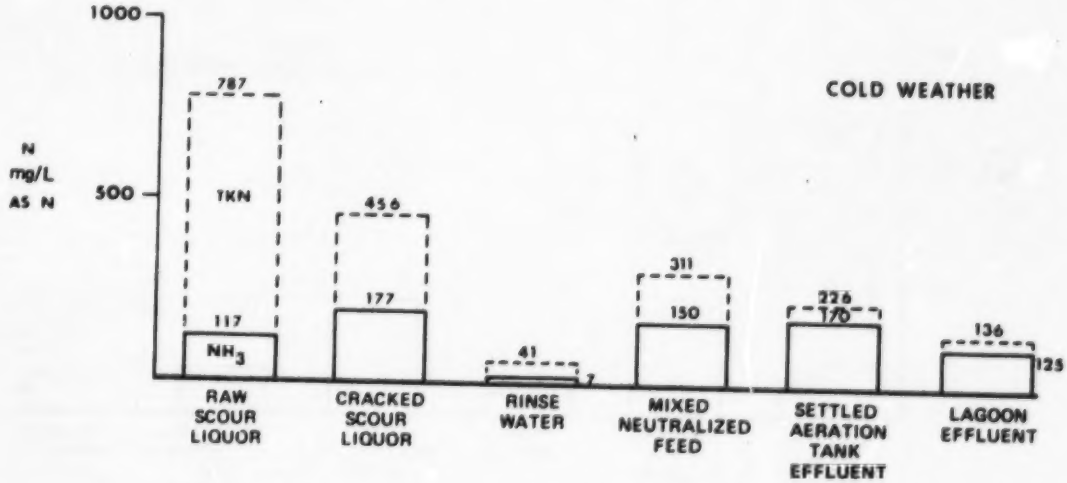


FIG. 12 NITROGEN THRU SYSTEM (COLD WEATHER)

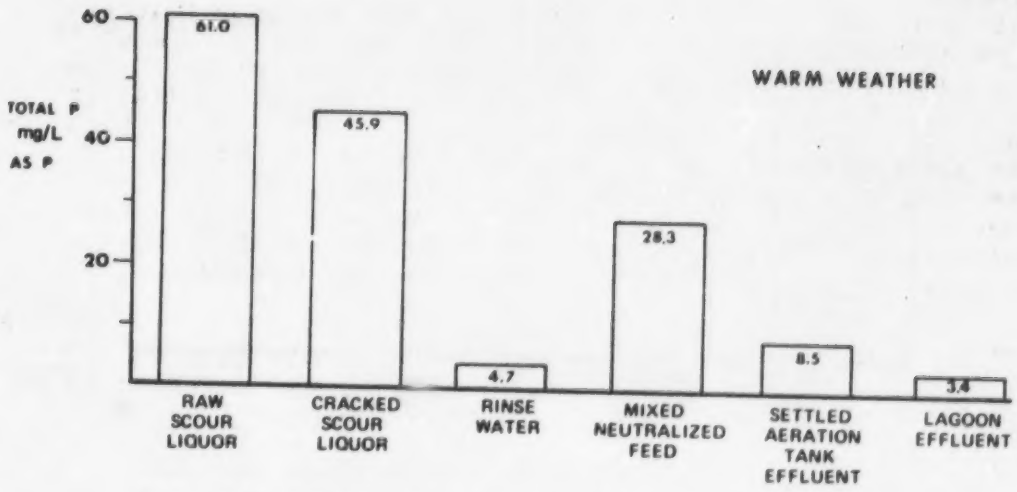


FIG. 13 PHOSPHORUS THRU SYSTEM (WARM WEATHER)

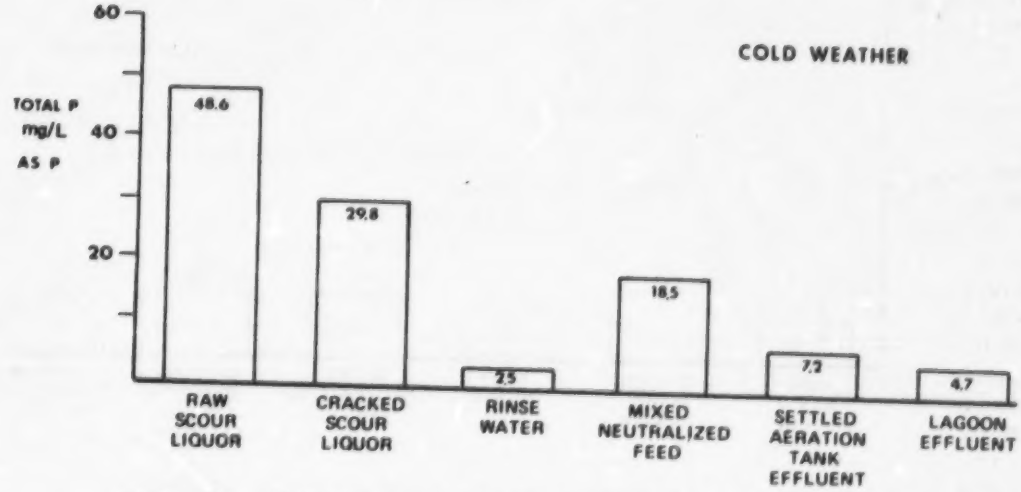


FIG. 14 PHOSPHORUS THRU SYSTEM (COLD WEATHER)

By comparing the raw scour liquor, cracked scour liquor, rinse water, and mixed neutralized feed for the warm and cold periods, the difference in influent waste characteristics as shown in Table 6 is clearly seen. With respect to the hot acid-cracking process, note the substantial drops in BOD and suspended solids resulting from the process as shown on Figures 7 through 10. A similar reduction in nitrogen and phosphorus can be seen on Figures 11 through 14; however, the decreases are not as significant. The fact that the nitrogen and phosphorus reductions are of lesser magnitudes than the BOD and suspended solids indicates the more soluble nature of the nitrogen and phosphorus.

The removal of BOD and phosphorus in the biological processes in warm and cold weather are very good. This is seen by comparing the mixed neutralized feed, settled aeration tank effluent, and lagoon effluent BOD and phosphorus levels as shown on Figures 7, 8, 13, and 14.

The settled aeration tank effluent suspended solids levels shown on Figures 9 and 10 indicate either a poor settling sludge or improper settling tank selection. Settling tests were run on the mixed liquor. A typical settling curve is shown on Figure 15. Based on an analysis of the settling velocity as outlined by Rich,[15] a maximum overflow rate of 8 $m^3/m^2/day$ (200 gpsf/day) was calculated.

Since the pilot clarifier operated at 3.5-4.1 $m^3/m^2/day$ (85-100 gpsf/day) and settling was rather rapid once agglomeration occurred, the poor settling could have been a result of clarifier design. Metcalf & Eddy has determined through experience that the clarifier side water depth (swd) should be 3.6 m (12 feet) minimum. The pilot plant settling tank had a 1.5 m (5 feet) swd. This rather shallow depth was dictated because of groundwater conditions which prevented deep tank installations. Also, construction costs prevented building the tanks at levels far enough above the existing grade to install a clarifier with a 3.6 m swd. If a 3.6 m swd had been provided, it is safe to assume that the aeration tank settled effluent suspended solids level would have been much lower.

The unit was not operated at or near 10 days' detention time as suggested by the 1969 Metcalf & Eddy report for two reasons:

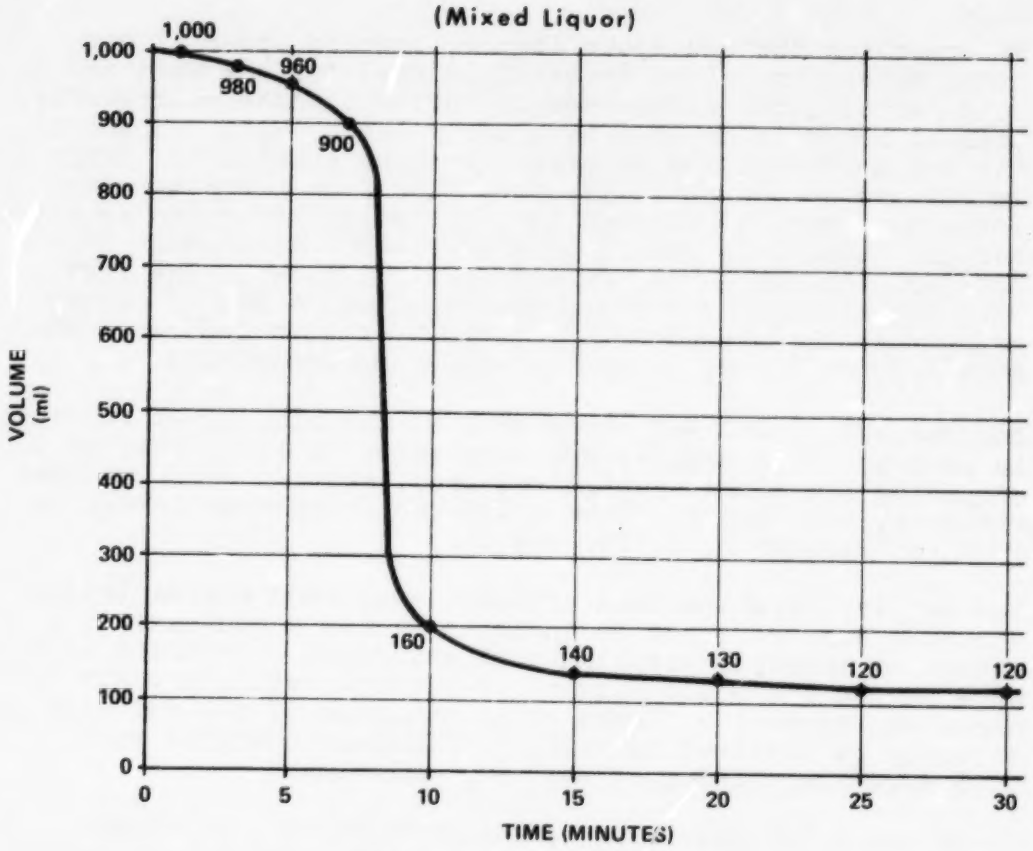


FIG. 15 SETTLING CURVE

1. A higher rate of oxygen uptake than anticipated due to the low alpha and beta limited BOD loadings in order to maintain a mixed liquor dissolved oxygen level of 1 mg/L.

2. The low residual dissolved oxygen levels during warm weather forced lower BOD loadings in an effort to maintain aerobic conditions. Since loadings and detention were related by flow, the lower loading increased detention times.

With respect to the biological plant, a few operating guidelines should be emphasized.

1. During warm weather, the ability to maintain a residual dissolved oxygen level was very difficult. This can be attributed to low alpha and beta values.

2. The use of surface aerators in areas of extreme cold should be cautiously considered (mixed liquor temperature fluctuations lagged behind air temperature changes by only one day, resulting in rapid lowering of water temperatures which increased icing problems).

3. Foaming in the aeration tank during cold weather was excessive with 0.6-1.2 m of foam on the water surface when water temperature dropped to 0-2 deg C.

The effluent characteristics and removal efficiencies for the biological process options previously shown on Figure 6 are shown in Table 8.

A comparison between the warm and cold weather performance with and without the stabilization lagoon as previously described and the existing lagoon treatment system will now be made. Data was gathered on the performance of the existing lagoons during only cold weather. For purposes of this comparison, a flow of 8,500 $m^3$/day (225,000 gpd) was used (consisting of 60 percent scour water and 40 percent rinse water to duplicate present plant conditions). Based on the performance of the existing lagoon system, shown on Figure 16, and the removals demonstrated by the two options shown on Figure 6, the river loadings shown in Table 9 can be developed. This clearly indicates the superiority of the proposed treatment, especially with the lagoon, over the existing method of treatment.

Based on the performance of the existing lagoons and the pilot plant system, another comparison of particular concern can be made, i.e., how do the two treatment systems compare with the Draft Proposed Effluent Limitations for the Refuse Act Permit Program[16] released on September 22, 1972 by the Environmental Protection Agency. The results of this comparison are shown in Table 10. This table reinforces the need for the stabilization lagoon in both warm and cold weather. It can be hypothesized from the previously mentioned settling tests that if a properly designed secondary settling tank were used, the solids levels in the effluent without using the lagoon would be much lower, in the range of 3.6-4.5 kg (8-10 lb) of solids per 453 kg (1,000 lb) of product.

Table 8. PILOT PLANT SETTLED AERATION TANK EFFLUENT AND LAGOON EFFLUENT CHARACTERISTICS UNDER WARM AND COLD TEMPERATURE EFFECTS

| | Without lagoon | | | | With lagoon | | | |
|---|---|---|---|---|---|---|---|---|
| | Warm | | Cold | | Warm | | Cold | |
| | mg/L | % Removal | mg/L | % Removal | mg/L | % Removal | mg/L | % Removal |
| TS | 15,000 | 20 | 13,040 | 17 | 8,580 | 57 | 8,780 | 43 |
| SS | 1,090 | -290 | 860 | -210 | 90 | 74 | 170 | 41 |
| BOD | 470 | 84 | 190 | 92 | 280 | 91 | 210 | 92 |
| COD | 3,350 | 56 | 2,400 | 64 | 1,620 | 80 | 1,580 | 76 |
| TKN | 320 | 17 | 230 | 27 | 140 | 62 | 140 | 54 |
| $NH_3$-N | 200 | -24 | 170 | -13 | 100 | 50 | 125 | 26 |
| Total P | 8.5 | 69 | 7.2 | 59 | 3.4 | 89 | 4.7 | 77 |

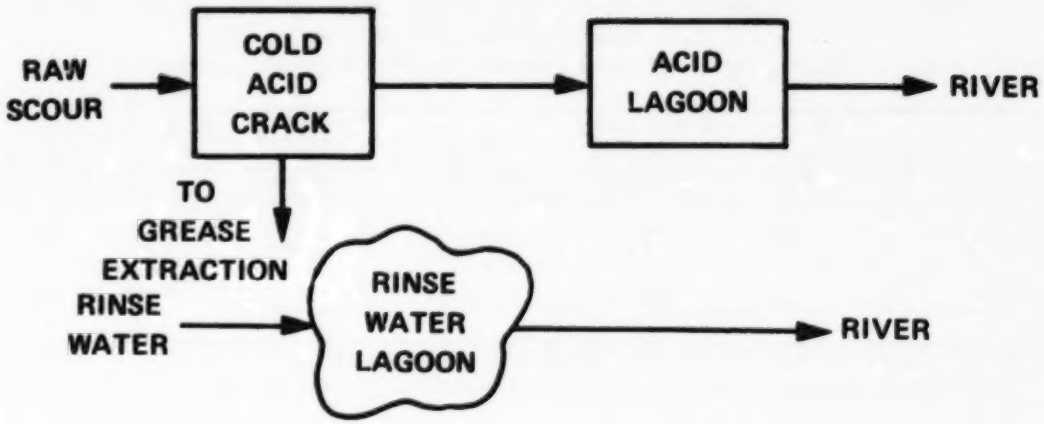


FIG. 16 SCHEMATIC OF EXISTING TREATMENT

Table 9. COMPARISON OF PROPOSED AND EXISTING TREATMENT IN COLD WEATHER
(Kilograms of discharge to river based on plant flow of 8,520 $m^3$/day)

| Pollutant to stream | Existing system kg | Proposed system: Without lagoon kg | Without lagoon % Decrease from existing | Proposed system: With lagoon kg | With lagoon % Decrease from existing |
|---|---|---|---|---|---|
| TS | 12,188 | 11,334 | 7 | 7,633 | 37 |
| SS | 734 | 747 | 2 | 149 | 80 |
| BOD | 2,849 | 165 | 94 | 181 | 94 |
| COD | 8,965 | 2,084 | 77 | 1,373 | 85 |
| TKN | 254 | 199 | 21 | 122 | 52 |
| $NH_3$ | 59 | 149 | 153 | 109 | 85 |
| Total P | 14 | 6 | 56 | 4 | 71 |
| Grease | 498 | 28 | 94 | 10 | 98 |

Table 10. COMPARISON OF EXISTING AND PROPOSED TREATMENT TO EPA GUIDELINES ISSUED 9/22/72
(Kilograms of pollutant/1,000 kg of product)

| | EPA proposed[a] | | Existing lagoons | Proposed system | | | |
|---|---|---|---|---|---|---|---|
| | | | | Without lagoon | | With lagoon | |
| | "A" | "B" | (Cold) | (Cold) | (Warm) | (Cold) | (Warm) |
| TSS | 8 | 10 | 24.9 | 25.4 | 32.2 | 5.1 | 2.6 |
| BOD | 8 | 20 | 96.8 | 5.6 | 13.9 | 6.2 | 8.2 |

[a]"A" limits are desired maximum discharge; "B" limits are maximum allowable discharge under circumstances.

With reference to Table 10, if the previously mentioned settling data is considered, it would be possible for the system without the lagoon to meet the proposed Class B discharge standards in either summer or winter. With the use of the lagoon, proposed Class A discharge standards could be met throughout the year.

In general, the biological treatment systems tested more adequately removed the pollutants than the existing lagoon system. Activated-sludge treatment followed by lagooning provides the more satisfactory alternative of the two options studied.

GREASE REMOVAL

The original concept in operating the hot acid-cracking system was to crack two or three batches of raw scour liquor, dump them into the settling tank, let the liquor cool, the grease settle, and then decant the cracked scour liquor for mixing and neutralization. It was found that a better quality of cracked scour liquor (much clearer, therefore less grease and solids) could be obtained if the cracked scour liquor from the first batch dropped each day was drawn off before the dumping of any more cracked material into the same settling tank.

Comparing the hot and cold acid-cracking processes, the major difference between the two systems is the one hour of boiling following acidification. This more completely breaks the grease-water emulsion formed by the nonionic detergent during scouring. The effluent characteristics of the two processes are shown in Table 11. From the point of

biological treatment, the hot acid cracking provides a more desirable waste because of much lower grease, BOD, and COD levels since unit loadings are reduced substantially.

Table 11. TYPICAL HOT AND COLD ACID-CRACKING PROCESS EFFLUENT CHARACTERISTICS, mg/L

| | Cold acid cracking | Hot acid cracking |
|---|---|---|
| BOD | 6,400 | 3,930 |
| COD | 24,000 | 12,500 |
| SS | 4,500 | 280 |
| TS | 24,800 | 27,100 |
| Grease | 3,200 | 110 |
| PNS | 120 | <40 |
| $NH_3$-N | 130 | 210 |
| TKN | 590 | 700 |
| Total P | 40 | 40 |

SUMMARY

After evaluating the grease extraction process and biological system individually and collectively, the results of the project should be reviewed:

1. The biological plant should be designed using these parameters:
   a. 20 days' detention time
   b. F/M ratio of 0.03-0.05
   c. Aeration tank loading of 49.3 grams/$m^3$/day (10 lb/1,000 cf/day)
   d. $\alpha = 0.54$, $\beta = 0.86$

e. Clarifier overflow of 8.2 $m^3/m^2$/day (200 gpsf/day)

f. Stabilization lagoon detention time of 50-60 days.

2. Cold weather does affect both aeration tank and stabilization lagoon performance adversely, but adequate treatment is provided when unit loadings are properly controlled and sufficient oxygen is provided.

3. The waste biological sludge produced is difficult to dewater, but can be disposed of using either lagoons or properly drained filter beds.

4. Hot acid cracking is superior to cold acid cracking with respect to loads exerted on subsequent treatment facilities and with respect to grease quantities made available for grease extraction processes.

## SECTION VII

## SPECIAL STUDIES

### WASTE SLUDGE

Extended aeration processes do not normally produce large amounts of waste sludge. This is because most solids are consumed during residence in the aeration tank. For the study period, August 29, 1972 through January 5, 1973, waste biological sludge amounted to 906 kg (2,000 lb). The plant flow was 454 $m^3$ (120,000 gal.) during this time. Of this 906 kg (2,000 lb), 453 kg (1,000 lb) was in the settled aeration tank effluent and 453 kg was wasted to the sludge lagoon. Wasting to the sludge lagoon occurred during one 3-week period, October 24 to November 14, 1972. This period coincides with a trend to moderating water temperatures and decreasing DO levels in the aeration tank. There was a decrease in the influent nutrient and food levels immediately before and during the early part of this 3-week period. Reflecting these conditions was a drop in the mixed liquor volatile suspended solids in the first of the 3 weeks.

The sludge blanket in the secondary settling tank rose to the weir and increasing the return sludge rate did not lower the blanket. In an effort to drop the sludge blanket and improve the quality of the settling tank, periodic wasting was initiated. This did lower the effluent suspended solids concentration. This wasting was discontinued once an equilibrium condition was reached.

### SLUDGE DISPOSAL

Two methods of sludge disposal were considered - lagooning and landfill. To facilitate land disposal, two methods of solids concentration were considered; vacuum filtration and centrifugation.

During the three weeks of sludge wasting, the waste sludge was tested for total solids and total volatile solids. After the sludge had been in the lagoon for 9 weeks from the date of the last wasting, the sludge was analyzed for total solids, total volatile solids, and grease. The comparison of the sludge composition is shown in Table 12. The data indicates that lagooning does not satisfactorily dewater the sludge.

Table 12. COMPARISON OF WASTED AND LAGOONED SLUDGES

| | Average of wasted sludge | Lagooned sludge after 2 months |
|---|---|---|
| Total solids, mg/L | 73,000 | 106,000 |
| Total volatile solids, mg/L | 41,000 | 65,000 |
| Grease, as percent of total solids | ND[a] | 4.7% |

[a]ND - Not Determined.

The return sludge sampling connection ruptured on one occasion creating a substantial pool of sludge on the sandy embankment around the aeration tank. This pool was 5 centimeters (cm) (2 in.) thick and covered 4.6 square meters ($m^2$) (50 sq ft). With the excellent drainage provided by the sand, the sludge dried into a firm, dry cake in 3 to 4 weeks.

The second means of sludge disposal studied was vacuum filtration. Prior to filtration, the sludge is normally treated with a coagulant and/or a coagulant aid. This treatment aids the filtration process by chemically causing the solids to agglomerate into larger masses, thereby rendering the liquid and solid portions more distinct.

Prior to launching a full series of Buchner Funnel Tests and Filter Leaf Tests, a Triton apparatus was used to screen coagulants and coagulant aids. This instrument, produced by Electronics Limited, Essex, England, measures the capillary suction time (C.S.T.), a relative measure of the rate at which water is released from a sludge under the force of gravity. A photograph of the instrument is shown on Figure 17 and a schematic of the testing stage is shown on Figure 18.

A sample of sludge, treated with the desired coagulant dosage, is poured into the stainless-steel tube. The water in the sludge drains into the filter pad. As the water spreads outward from the tube, it contacts two electrical sensors on the inner concentric circle, labeled 1. This starts the timer. As the water continues to spread through the filter pad, it contacts another sensor on the outer

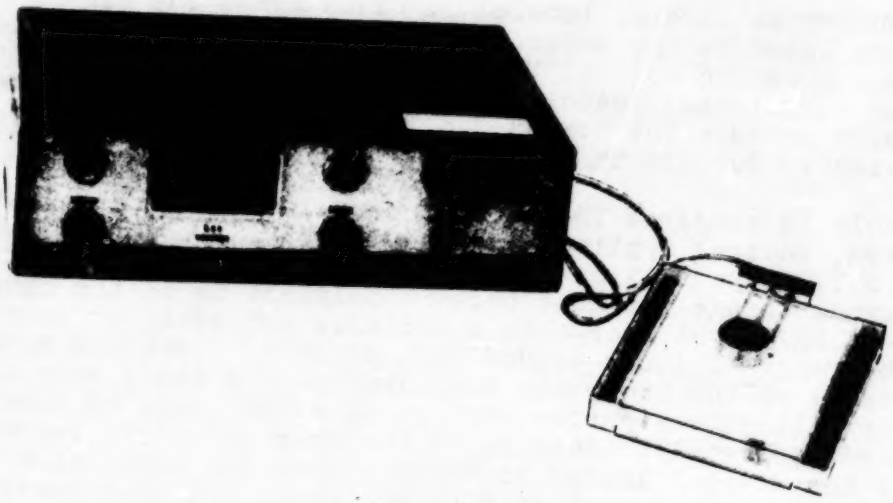

FIG. 17 TRITON APPARATUS

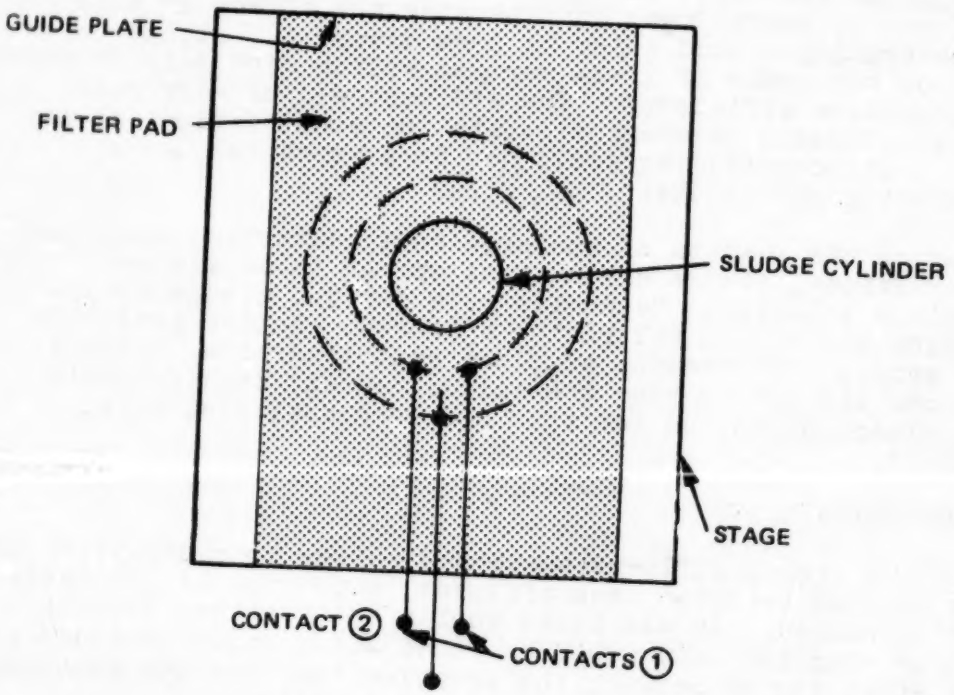


FIG. 18 TESTING STAGE OF TRITON APPARATUS

concentric circle, labeled 2. This stops the timer. The time taken by the water to travel from Contact 1 to Contact 2 is the C.S.T. Using this comparison of C.S.T.'s, the coagulants, coagulant aids, and combinations thereof which produce the lowest C.S.T.'s can be more readily selected for use in the filter leaf test.

Table 13 compares the various coagulants and coagulant aids used, dosages applied, and resultant C.S.T.'s. A "good" C.S.T. is usually on the order of 10 seconds or less. The normal dosage for most organic polymers is in the range of 0-20 mg/L, but inorganic coagulants can often be used in the range of 1,000-20,000 mg/L or more. Often, a moderate dosage of the inorganic coagulant plus a small dose of polymer will give superior results to either type of treatment used separately. Because of the chemical costs represented by the dosages listed in Table 13 and the respective C.S.T.s, further studies such as Buchner Funnel and Leaf Tests were not conducted.

Samples of the waste sludge were also given to a major manufacturer of centrifuges to determine the effect of this concentrating method prior to land disposal. Sludge cakes were on the order of 12-14 percent solids with only 50 percent capture efficiency. The effluent was of very poor quality. Based on chemical costs for conditioning, it was felt that centrifuging would not be a practical means of dewatering the sludge.

Based on the results of the previously described tests and observations, sludge drying beds appear to be the most feasible solution. Economics rule out the sludge conditioning and vacuum filtration approach. Solids production and general performance preclude centrifugation. Sludge lagoons did not improve the solids content significantly. The sludge drying on the sand did work satisfactorily, however.

## COAGULATION TESTS

With the rising effluent suspended solids concentrations in the settled aeration tank effluent, a program of jar tests was initiated. It was hoped that a satisfactory coagulant and/or coagulant aid would be found which could be added to the mixed liquor between the aeration tank and the settling tank to aid in removing the suspended solids.

Table 13. SUMMARY OF SLUDGE CONDITIONING TESTS

| Conditioning agent | Dosage, mg/L | C.S.T., sec |
|---|---|---|
| 1. Atlas 2A2 | 0.2 | >120 |
| 2. Atlas 2A2 | 0.6 | >120 |
| 3. Atlas 2A2 | 1.0 | >120 |
| 4. Rohm & Haas C-7 | 0.2 | >120 |
| 5. Rohm & Haas C-7 | 0.6 | >120 |
| 6. Rohm & Haas C-7 | 1.0 | >120 |
| 7. American Cyanamid Magnifloc 905N | 0.6 | >120 |
| 8. American Cyanamid Magnifloc 905N | 1.0 | >120 |
| 9. Magnifloc 521C | 10.0 | >120 |
| 10. Magnifloc 573C | 10.0 | >120 |
| 11. Magnifloc 575C | 10.0 | >120 |
| 12. Magnifloc 577C | 10.0 | >120 |
| 13. Calgon Cat-Floc B | 20.0 | >120 |
| 14. Calgon Cat-Floc B | 100.0 | >120 |
| 15. Calgon WT 2,660 | 20.0 | >120 |
| 16. Calgon WT 2,660 | 100.0 | >120 |
| 17. Calgon WT 2,870 | 20.0 | >120 |
| 18. Calgon WT 2,870 | 100.0 | >120 |
| 19. $FeCl_3$ | 1,000 | >120 |
| 20. $FeCl_3$ | 5,000 | 77.6 |
| 21. $FeCl_3$ | 10,000 | 30.4 |
| 22. Alum | 1,000 | >120 |
| 23. Alum | 6,000 | 92.1 |
| 24. Alum | 12,000 | 44.1 |
| 25. Lime | 5,000 | 99.0 |
| 26. Lime | 10,000 | 51.7 |
| 27. Lime | 20,000 | 34.1 |
| 28. Lime | 40,000 | 27.4 |
| 29. Lime<br>$FeCl_3$ | 20,000<br>10,000 | 29.4 |
| 30. Lime<br>$FeCl_3$ | 40,000<br>5,000 | 25.3 |
| 31. Lime<br>WT 2,870 | 20,000<br>20.0 | 55.5 |
| 32. Lime<br>WT 2,870 | 20,000<br>40.0 | 49.0 |
| 33. Lime<br>WT 2,870 | 20,000<br>60.0 | 46.0 |
| 34. $FeCl_3$<br>WT 2,870 | 10,000<br>20.0 | 58.1 |
| 35. $FeCl_3$<br>WT 2,870 | 10,000<br>40.0 | 75.6 |

Table 13 (Continued). SUMMARY OF SLUDGE CONDITIONING TESTS

| Conditioning agent | Dosage, mg/L | C.S.T., sec |
|---|---|---|
| 36. Lime | 20,000 | |
| Magnifloc 577C | 20.0 | 43.6 |
| 37. Lime | 20,000 | |
| Magnifloc 577C | 40.0 | 35.2 |
| 38. Lime | 20,000 | |
| Magnifloc 577C | 60.0 | 35.3 |
| 39. Lime | 20,000 | |
| Hercules 814.2 | 20.0 | 51.4 |
| 40. Lime | 20,000 | |
| Hercules 814.2 | 40.0 | 66.0 |
| 41. Lime | 20,000 | |
| Magnifloc 905N | 20.0 | 49.0 |
| 42. Lime | 20,000 | |
| Magnifloc 905N | 40.0 | 66.1 |
| 43. Lime | 20,000 | |
| Rohm & Haas C-7 | 20.0 | 58.0 |
| 44. Lime | 20,000 | |
| Rohm & Haas C-7 | 40.0 | 58.3 |

Using a Phipps and Bird Multiple Stirrer, mixed liquor samples were treated with various coagulants and coagulant aids, flash mixed for 1 minute at 90 revolutions per minute (rpm), slow mixed for 15 minutes at 20 rpm, and then allowed to settle for 15 minutes. Table 14 lists the chemicals tested and concentrations used.

Based on a visual comparison of floc formation, rapidity of settling, and clarity of supernatant produced, only alum used at a concentration of 2,000 mg/L showed any substantial improvement over the untreated mixed liquor. It was noted that the mixing procedures used in the testing did produce some flocculation without the addition of any coagulant. The zinc sulfate was used along with sodium hydroxide to test the effectiveness of zinc hydroxide, but this also proved unsuccessful.[17] The results of the testing did not provide any basis for adding a coagulant so this course was not pursued further.

Table 14. CHEMICAL AGENTS TESTED FOR IMPROVEMENT OF SETTLED AERATION TANK EFFLUENT

| | Chemical | Concentration, mg/L |
|---|---|---|
| 1. | Alum, $Al_2(SO_4)_3 \cdot 18\ H_2O$ | 0-2,000 |
| 2. | Calcium hydroxide, $Ca(OH)_2$ | 0-500 |
| 3. | Ferric chloride, $FeCl_3$ | 0-400 |
| 4. | Zinc sulfate, $ZnSO_4 \cdot 7\ H_2O$ | 0-500 as Zn |
| 5. | Atlas, 2A2 | 0-10 |
| 6. | Hercules 814.2 | 10 |
| 7. | Calgon, Cat-Floc B | 5-50 |
| 8. | Rohm and Haas, C-7 | 10 |
| 9. | American cyanamid, Magnifloc 905N | 10 |
| 10. | Cat-Floc B | 10 |
| | Alum | 50 |
| 11. | Cat-Floc B | 10 |
| | Alum | 100 |
| 12. | Cat-Floc B | 10 |
| | Alum | 200 |
| 13. | Cat-Floc B | 10 |
| | Alum | 250 |

## ALPHA DETERMINATIONS

In the design of an aerobic biological treatment system, the amount of oxygen input required to maintain satisfactory aerobic conditions is very important. During the operation of the pilot plant, alpha and beta values were determined several times. The results are summarized in Table 15.

Table 15. SUMMARY OF ALPHA AND BETA DETERMINATIONS

| | Range | Average |
|---|---|---|
| Alpha | 0.405 - 0.638 | 0.543 |
| Beta | 0.814 - 0.943 | 0.861 |

Since the amount of oxygen which must be supplied to an aerobic system is inversely proportional to alpha, it can

be seen that for decreasing values of alpha, the amount of oxygen supplied must increase.

Normally, alpha values are in the range of 0.8 to 0.9. For the design of our pilot plant, an alpha value of 0.75 was considered good. Since, in actuality, the value was much lower, it is understandable that the BOD loading had to be decreased and the oxygen supply increased.

PRODUCTION OF POLLUTANT VS. PRODUCT

The new discharge guidelines being considered by The Environmental Protection Agency consider the quantities of water consumed and waste produced per unit of product. Therefore, Table 16 was compiled to indicate the pollution load exerted on the river following biological treatment with and without the stabilization lagoon.

Table 16. POLLUTANT VS. PRODUCT

| Pollutant | Kilograms of pollutant discharged to river/1,000 kg of wool top produced[a] | | | |
|---|---|---|---|---|
| | Without lagoon | | With lagoon | |
| | Warm | Cold | Warm | Cold |
| BOD | 13.9 | 5.6 | 8.2 | 6.2 |
| TSS | 32.2 | 25.4 | 2.6 | 5.1 |
| COD | 96.8 | 69.3 | 46.8 | 45.6 |
| Grease | 0.9 | 0.9 | 0.3 | 0.3 |
| TKN | 9.2 | 6.6 | 4.0 | 4.0 |
| $NH_3$-N | 5.8 | 4.9 | 2.9 | 3.6 |
| Total P | 0.2 | 0.2 | 0.1 | 0.1 |

[a]Based on plant wastewater flow of 852 $m^3$/day (225,000 gpd) and wool top production of 29,500 kg (65,000 lb/day).

Table 17 is presented to show how hot acid cracking affects the flow stream contributions which are biologically treated. From Table 17, it can be seen that the hot acid-cracking

process substantially reduces the load on the biological treatment process. The reduction in suspended solids and grease is the most significant reduction. These tables also indicate that although the hot acid-cracking process removes a considerable amount of the BOD, COD, suspended solids, and grease, the nitrogen and phosphorus present in the waste are essentially unaffected. As stated in Section VI, however, the hot acid cracking and biological treatment with lagooning produces a much higher quality effluent for discharge into the river.

Table 17. KILOGRAMS OF POLLUTANT BEFORE AND AFTER HOT ACID CRACKING
(Based on scour liquor flow = 510 $m^3$/day and average stream concentrations for entire study period)

| Pollutant | Raw scour | Hot acid-cracked scour |
|---|---|---|
| BOD | 9,655 | 2,306 |
| SS | 19,171 | 145 |
| COD | 30,908 | 6,383 |
| TKN | 471 | 358 |
| $NH_3$-N | 82 | 109 |
| Total P | 32 | 23 |
| Grease | 6,772 | 54 |

## COLOR, COLIFORM AND CHLORINE DEMAND

In addition to characterizing the waste treatment effectiveness, a major goal of the pilot plant study was to determine guides for the design and operation of a prototype plant. Wool-scouring waste is normally a very rich brown and requires considerable dilution to limit the effect of this color on the receiving body of water. The Ware River was considered as the receiving stream. To maintain a color of 30 (American Public Health Association (APHA) units), it was necessary to provide a dilution factor of 800 to 1, river water to lagoon effluent.

The membrane filter test indicated that both biological effluent streams, with and without benefit of the stabilization lagoon, had total coliform levels from 10-340/100 ml. These levels are from unchlorinated streams.

The chlorine demand was determined by dosing samples of the effluent streams with 100 or 200 mg/L of chlorine and measuring the residual after 20 minutes. The difference between the dosage and residual was the chlorine demand. Both streams produced chlorine demands from 36-158 mg/L. Based on this wide range of demands, it would be wise to evaluate the demand frequently. Also, since the chlorine demand is so variable, each similar treatment system should be considered an individual and evaluated separately.

## DISSOLVED SOLIDS

Because of the high dissolved solids present, the three major flow streams in the biological treatment system were analyzed. The results of this testing are shown in Table 18. Notice that the sulfates comprise a major portion of the dissolved solids. Also, the calcium is present in substantial amounts. This indicates that the acidification and neutralization contributes much of the dissolved solids.

Table 18. DISSOLVED SOLIDS COMPOSITION

| | Aeration tank influent | Settled aeration tank effluent | Lagoon effluent |
|---|---|---|---|
| Total dissolved solids, mg/L | 16,330 | 11,500 | 4,370 |
| Chloride, mg/L | 206 | 35.5 | 84.5 |
| Iron, mg/L | 78.0 | 15.5 | 2.2 |
| Manganese, mg/L | 3.6 | 2.0 | 1.3 |
| Sulfate, mg/L | 7,300 | 6,400 | 2,220 |
| Calcium, mg/L | 950 | 800 | 270 |
| Magnesium, mg/L | 60 | 56 | 20 |

In looking at Table 18, the question which must be answered is how are the dissolved solids removed, not only in the aeration process but also in the stabilization lagoon. With respect to the aeration tank, it is possible that the cations combine with the sulfate ion forming insoluble compounds which would precipitate out in the settling tank. In the lagoon, anaerobic conditions would allow the sulfate to be reduced to sulfide. In the sulfide state, the calcium and manganese compounds of sulfide would be relatively insoluble, thus precipitating out in the lagoon. Another possibility is that during the synthesis of cell material that occurs in the lagoon, both soluble and insoluble forms are adsorbed and/or adsorbed by the cells which then could settle in the lagoon.

## SURFACTANTS

As mentioned in Section V, the nonionic detergent required the use of the polyoxyethylene nonionic surfactants (PNS) procedure rather than the more conventional "Methylene Blue Active Substance" determination. A comparison of PNS discharges for the various existing and proposed effluent streams is shown in Table 19. The degree of treatment supplied by the pilot plant's approach proved superior to the existing system with respect to the removal of nonionic surfactants. The hot acid-cracking process performance also is better than the present cold acid-cracking process with respect to reducing the PNS load on the biological system. The comparison is shown in Table 20.

Table 19. EFFLUENT STREAM PNS LEVELS

| | PNS, mg/L |
|---|---|
| Existing acid lagoon effluent | 27.0 |
| Existing rinse lagoon effluent | 6.0 |
| Settled pilot plant aeration tank effluent | 7.0 |
| Pilot plant lagoon effluent | <5.0 |

Table 20. COMPARISON OF PNS LEVELS FROM ACID-CRACKING PROCESSES

| | PNS, mg/L |
|---|---|
| Raw scour | 445 |
| Cold acid-cracked liquor | 128 |
| Hot acid-cracked liquor | 71 |

ARSENIC

During the pilot plant study, the Commonwealth of Massachusetts Water Resources Commission was conducting a survey of heavy metals in the bottom deposits of various streams. The discharge channel from the existing acid lagoon and the sludge from the bottom of the existing acid lagoon indicated arsenic levels of 7.6 mg/L and 11.4 mg/L, respectively. Based on these results, they asked for an indication of arsenic levels in the raw wastewater. Table 21 summarizes the results of a brief sampling program conducted at the end of the pilot plant study. The acidified wastewater arsenic was in a soluble form. The rinse water arsenic was from 60-100 percent soluble.

Table 21. ARSENIC LEVELS

| | Arsenic, mg/L |
|---|---|
| Raw wool scour | 0.5 |
| Rinse water | 0.1 |
| Cold acid-cracked scour liquor | 2.0 |
| Effluent from existing acid lagoon | 1.2 |
| Effluent from existing rinse water lagoon | 0.04 |
| Pilot plant mixed liquor | 0.27 |

Arsenic has been found to be toxic to rotifers at concentrations of 4 mg/L.[18] Since the arsenic is in a highly soluble state, it is most likely the result of a highly soluble arsenic compound such as $NaAsO_2$ or $Na_2HAsO_4$ being used in a sheep-dip mixture. Although not an apparent source of trouble, the arsenic levels should be checked periodically in at all points in the wastewater treatment process. Also, the groundwater arsenic levels near the landfill sites receiving the sludge from the grease processing should be checked since most drinking water in the area is derived from wells.

## SECTION VIII

## COST ESTIMATE

Based on the criteria listed in Table 22, the full-scale hot acid-cracking plant and biological treatment facilities' capital costs can be estimated. The cost estimate for the hot acid-cracking plant was adjusted based on ENR Construction Index[19] changes since the initial figures were done in 1969-1970. The biological facility costs were arrived at using an estimating manual published for the Technology Transfer Program of the United States Environmental Protection Agency[20] with proper ENR adjustment.

Table 22. DESIGN CRITERIA

1. Flow 950 $m^3$/day (250,000 gpd) (510 $m^3$/day) to hot acid cracking)
2. Aerators supply 1.8 kg of oxygen/kilowatt-hour (kwh) (3 lb of oxygen/hp/hr)
3. Biological unit designed on:
   a. BOD loading to aeration tank 48.8 grams/$m^3$/day (10 lb/1,000 cf/day)
   b. $\alpha = 0.54$ $b = 0.86$
   c. 20 days' aeration time
   d. Clarifier overflow of 8.2 $m^3/m^2$/day (200 gpsf/day)
   e. Stabilization lagoon detention 50-60 days
4. ENR Construction Index = 1900
5. Capital costs amortized over 20 years at an interest rate of 6-3/4 percent
6. No engineering fees considered

With conditions as previously mentioned, the capital costs are as follows:

| | |
|---|---|
| Hot acid-cracking plant | $ 400,000 |
| Biological plant (including aeration, settling, stabilization, chlorination, influent pumping, sludge pumping, necessary appurtenances, and sludge drying beds) | 968,600 |
| Total | $1,368,600 |

The annual operating and maintenance (O&M) costs include manpower, chemicals, repairs, power, fuel for steam generation, etc. For each portion of the facility, the costs are:

| | |
|---|---|
| Hot acid cracking, O&M | $ 274,600/yr |
| Biological plant, O&M | 160,800/yr |
| Total | $ 435,400/yr |

Amortizing the above capital costs and adding O&M costs, the annual expenditures can be determined:

| | |
|---|---|
| Hot acid-cracking plant annual capital cost | $ 31,500 |
| Hot acid-cracking annual O&M | 274,600 |
| Subtotal | $ 306,100 |
| Biological plant annual capital cost | 76,200 |
| Biological plant annual O&M | 160,800 |
| Subtotal | $ 237,000 |
| Total | $ 543,100 |

## SECTION IX

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## SECTION X

## ABBREVIATIONS

| | |
|---|---|
| ALK | alkalinity |
| APHA | American Public Health Association |
| BOD | biochemical oxygen demand |
| cf | cubic feet |
| COD | chemical oxygen demand |
| CPVC | chlorinated polyvinylchloride |
| CST | Capillary Suction Time |
| deg | degrees |
| DO | dissolved oxygen |
| ENR | Engineering News Record |
| F/M | food-to-microorganisms ratio |
| ft | feet |
| gpsf | gallons per square foot |
| hp | horsepower |
| hr | hour |
| kg | killigrams |
| kw | kilowatt |
| khw | kilowatt-hour |
| m | meter |
| mg/L | milligrams per liter |
| mμ | millimicrons |
| O&M | Operation and Maintenance |

| | |
|---|---|
| $NH_3$-N | ammonia as nitrogen |
| $NO_2$-N | nitrite as nitrogen |
| $NO_3$-N | nitrate as nitrogen |
| PNS | polyoxyethylene nonionic surfactants |
| RFP | reinforced fiberglass plastic |
| SS | suspended solids |
| swd | side water depth |
| TKN | Total Kjeldahl Nitrogen |
| TOC | total organic carbon |
| TS | total solids |
| VSS | volatile suspended solids |

*U.S. GOVERNMENT PRINTING OFFICE:1973 546-316/261 1-3